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Fiber Raman Amplifier Development for Laser Absorption Spectroscopy Measurements of Atmospheric Oxygen near 1.26 Micron

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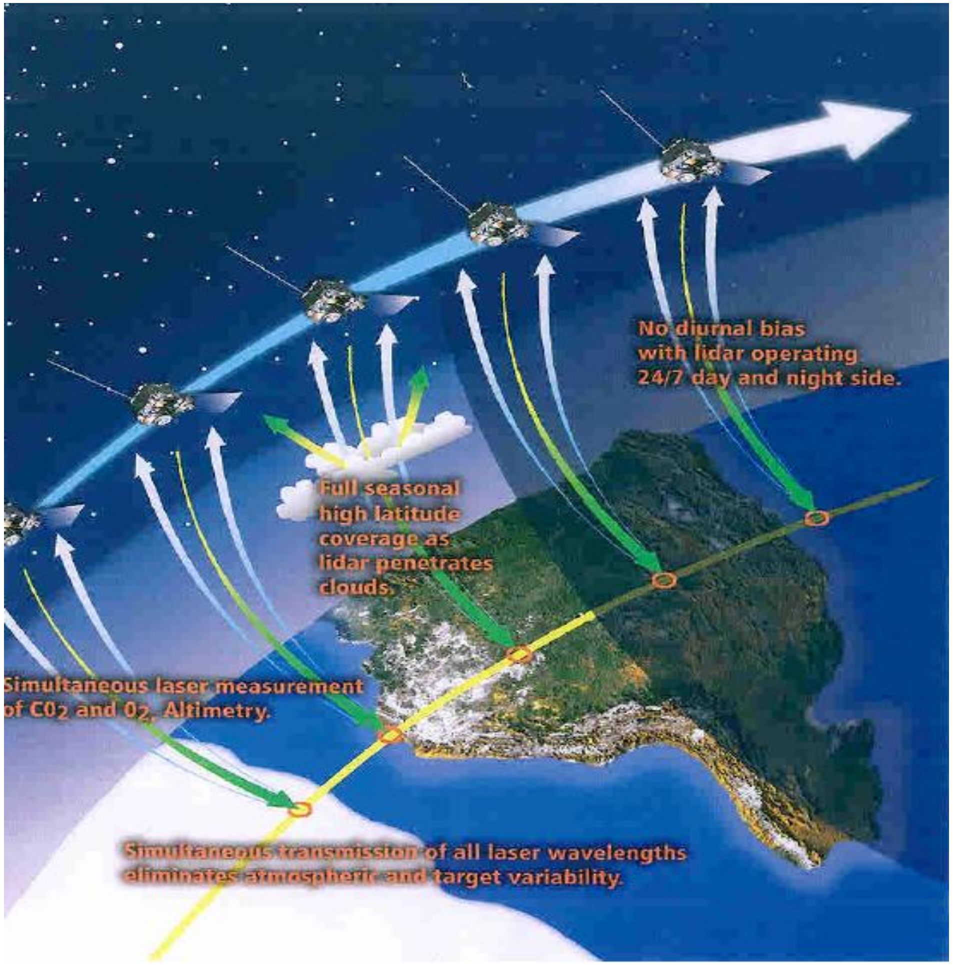
Overview

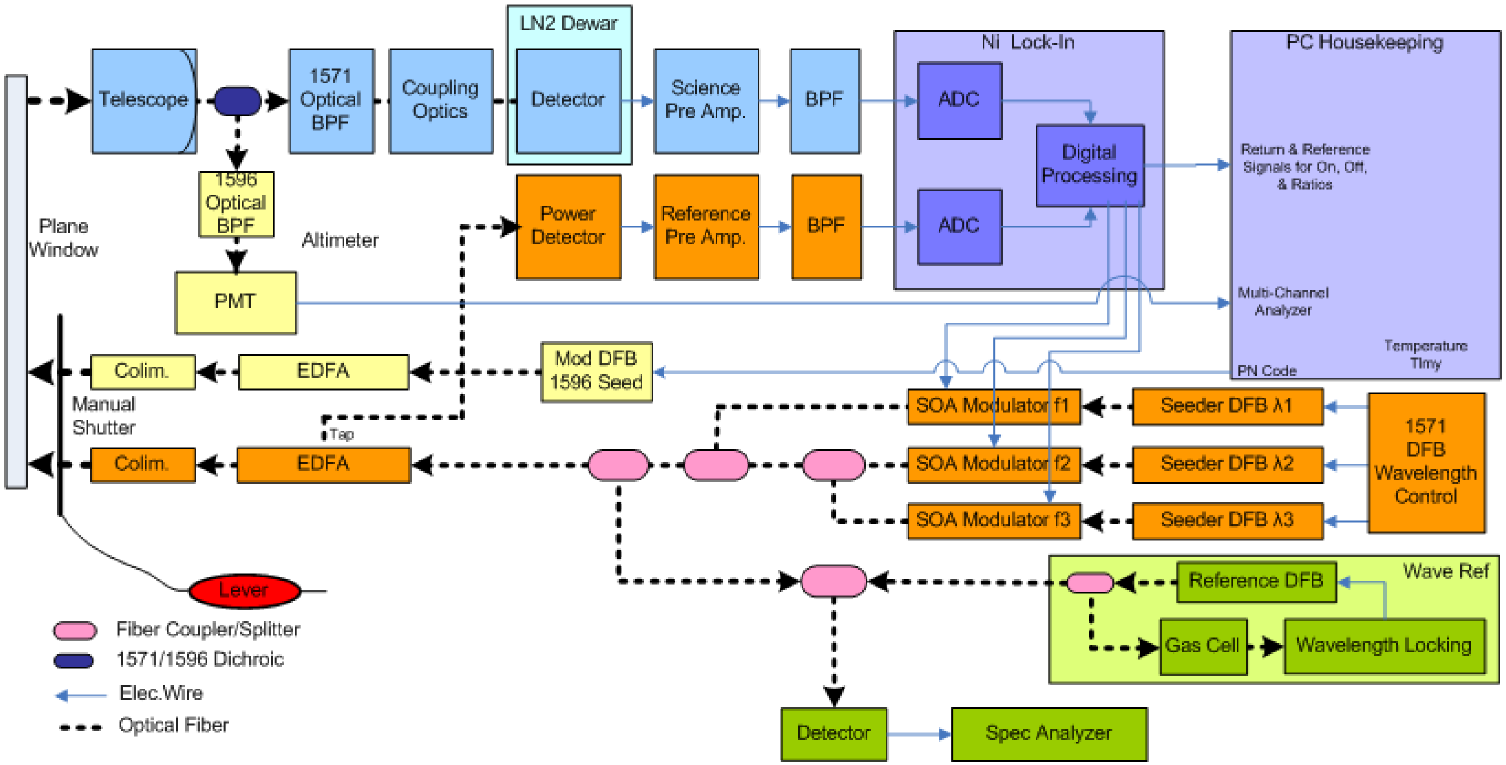
- Multifunctional Fiber-Laser Lidar (MFLL) overview
- Recent CO_2 work
- Raman amplifier development
- Ground testing
- Preliminary results
- Current and future work

Active Sensing of CO_2 Emissions over Nights, Days and Seasons [ASCENDS]: A Multi-Functional Fiber Laser Lidar for Climate Variability and Atmosphere Composition

- Comprehensive Instrument Suite:
  - CO_2 Lidar
  - O_2 Lidar
  - PN Laser Ranger
  - Passive Temperature Sounder
  - Passive CO Sensor
  - Dedicated Payload



CO_2 EDU Instrument Overview



- Simultaneous transmit/receive of all wavelengths
- Software based digital lock-in separates channels
- Leverages highly reliable CW telecom laser components
- No free space optics allows for rugged design

EDU Flight History

ITT EDU

Lear-25

UC-12

DC-8

The CO_2 EDU has been deployed in 10 flight campaigns since May 2005; with more than 50 flights spanning 3 different aircraft. Flights have been conducted over various land types and over water, during both day and night operations. Recent results for the CO_2 instrument as compared to high precision in-situ data have shown absolute comparisons to better the 0.5 ppm with standard deviation of ~2ppm.

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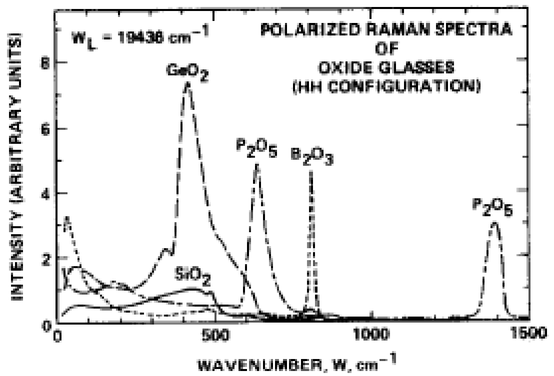
Fiber Raman Amplifier Objectives

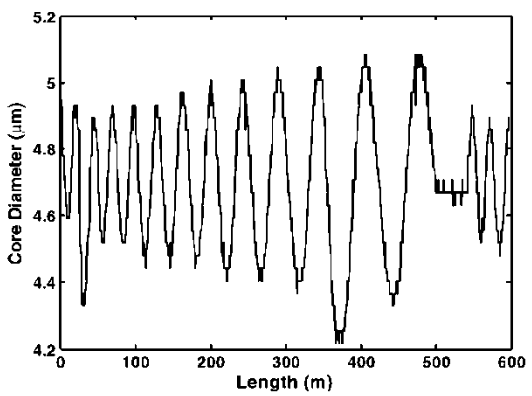
- Amplify a 50 kHz or greater modulated CW 1.26-1.27 µm seed signal to Watt level average power (5 W goal)
- Simultaneously transmit online and offline wavelengths
- Design fibers to suppress stimulated Brillouin scattering (SBS) to allow for narrow linewidth amplification
  - Varying core diameter
  - Reduce overlap between optical and acoustic modes
- Simple, efficient, and robust architecture

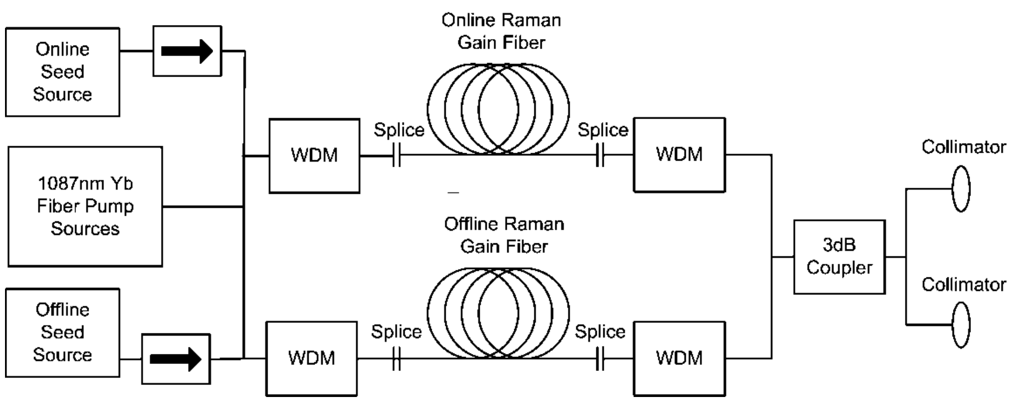
First Generation Fiber Raman Amplifier



Galeener, et. al., Apl. Phys. Lett., **32**, 34, 1978.

- Core variation broadens SBS spectrum by 50 MHz for ~3 dB SBS suppression
- 1.8 W average power achieved
  - 2.4 W peak online (~30% optical efficiency)
  - 0.58 W peak offline (~10% optical efficiency)





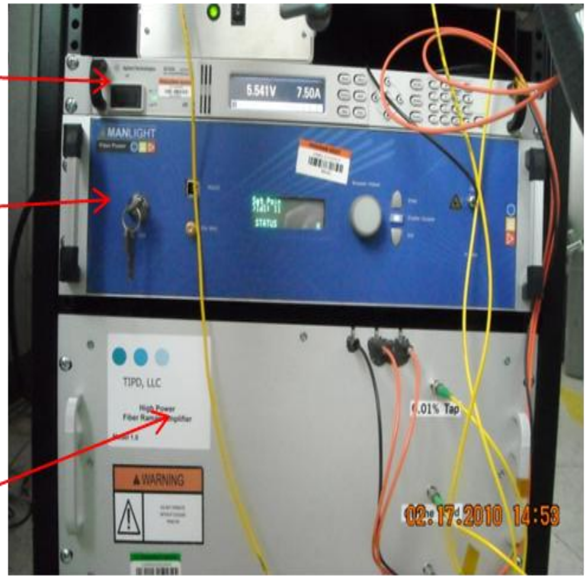
Nagel, et. al., IEEE Photon. Technol. Lett., **23**, 585, 2011.

First Amplifier and Test Setup

Nufern Amp PS

Pump laser and seed for Nufern amp

Raman Fiber Amplifier (80% of size is driven by Nufern Amp and heat sink



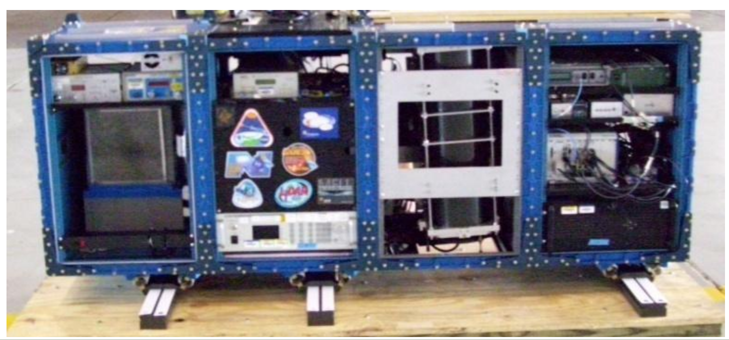
Online Wavemeter

Offline Wavemeter

DFB's and SOA's

Custom modulator

Data acquisition and control done through integration with ITT CO_2 EDU



After Integrating With the EDU Tests Were Performed at ITT's Ground Test Facility

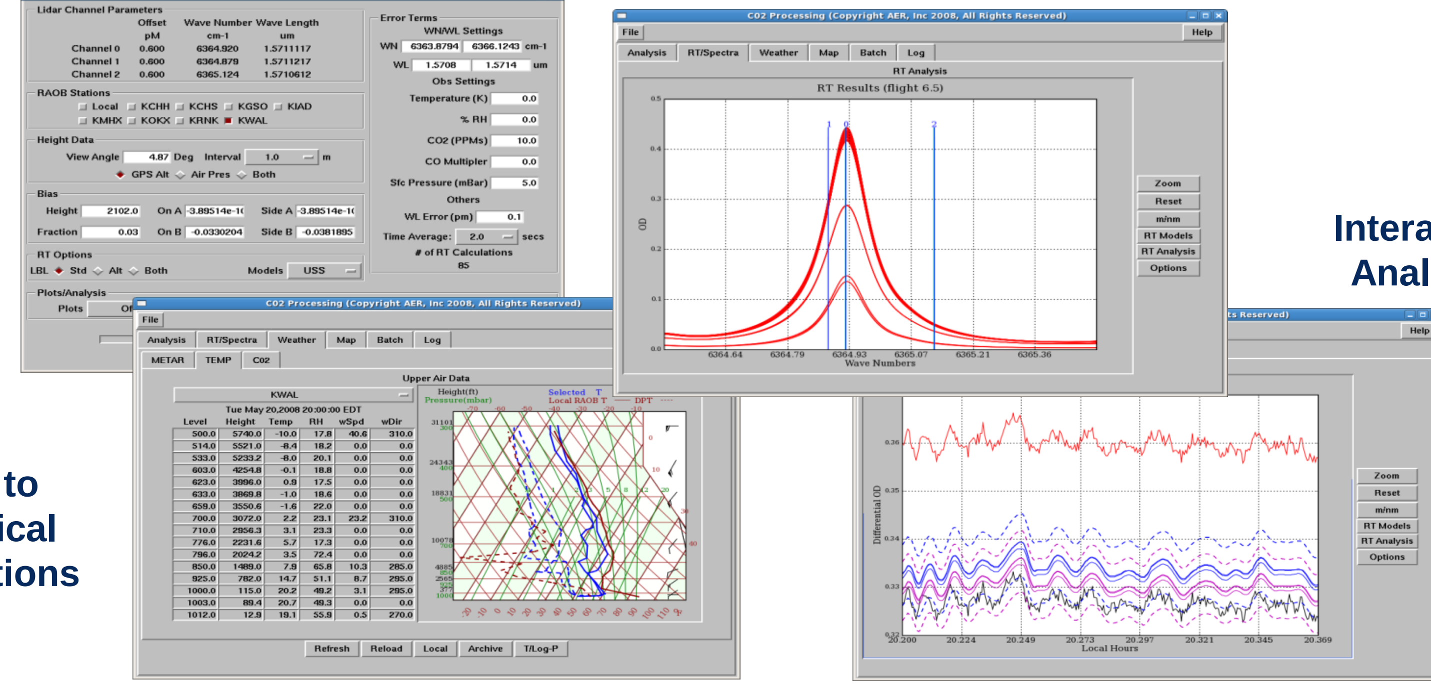
AER's End-to-End Analysis Software, Previously Developed For the CO_2 EDU was Updated to Include O_2

User-Defined Model Results

Ingest/Analysis Interface

Interactive Analyses

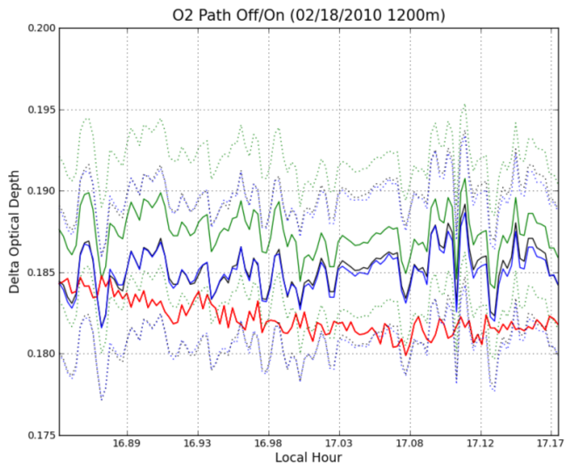
Web Interface to Current/Historical Weather Conditions

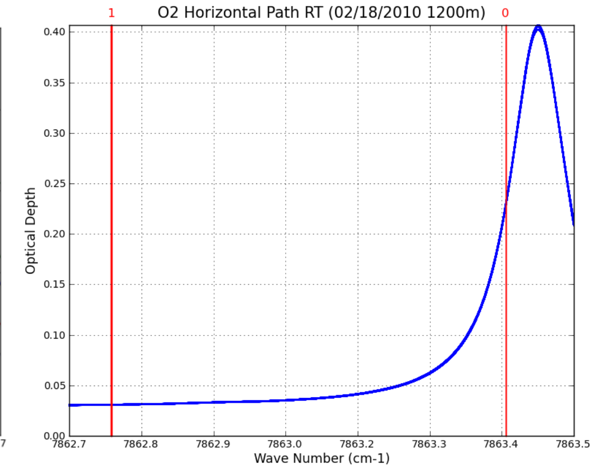


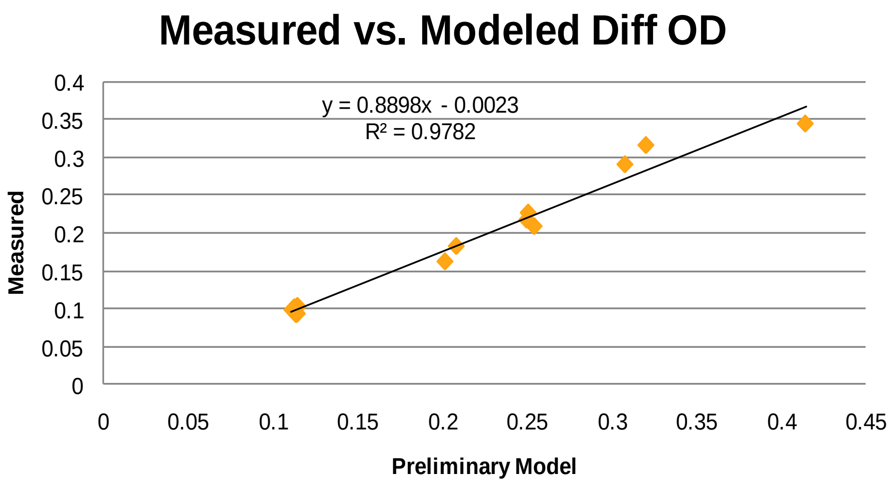
The data is fed into LBLRTM to generate values of optical depth for a given pressure, temperature, relative humidity, and distance to target. The values for optical depth are computed in wavelength range of the IPDA instrument, and values for online/offline optical depth are selected based upon the measured wavelengths provided by the IPDA system. The difference between online and offline optical depths are taken to compare with measurements of differential optical depth taken with the IPDA.

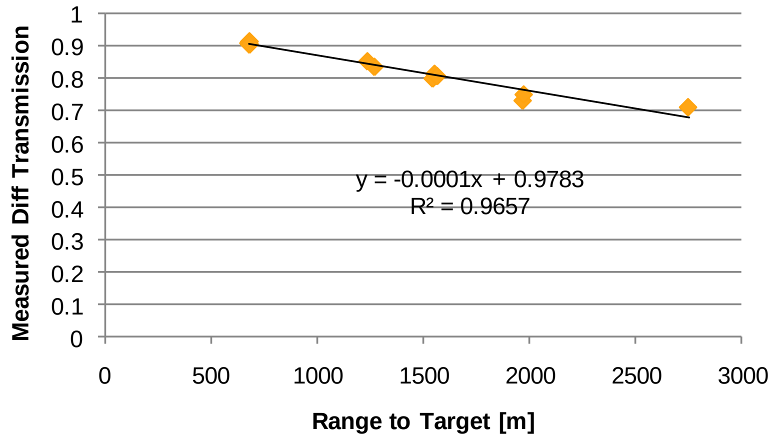
Initial Testing Results First Gen Amplifier

- Measurements were made over ranges from 600 m – 2.7 km
- The preliminary model comparisons show good correlation with the O_2 IPDA measurements

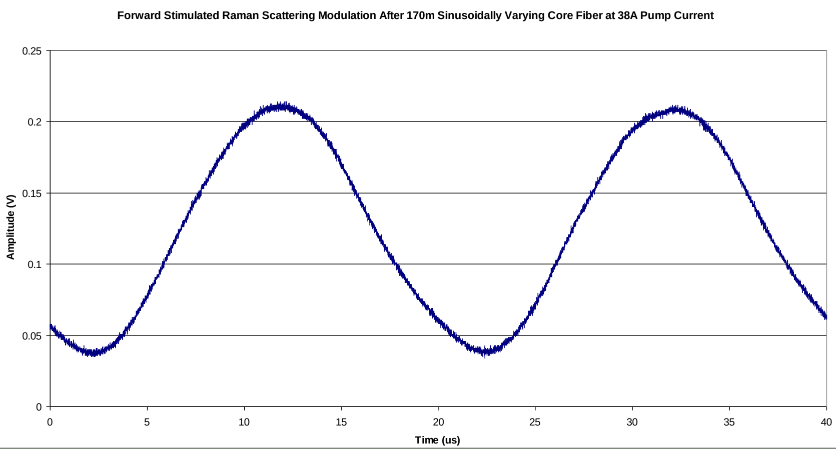








Second Generation Fiber Raman Amplifier

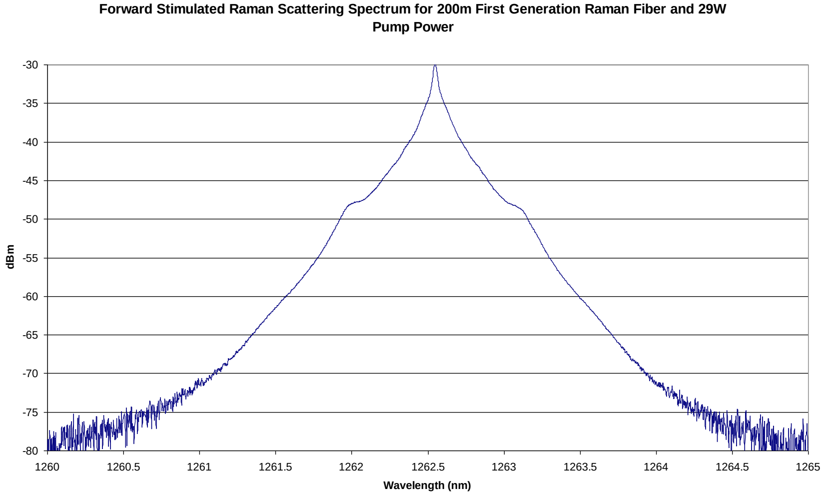


- Reduced size by 2X
- Reduced weight by 40 lbs
- Reduced power by 110 VA
- Forward pumping produced 13.2 W peak with 3 db bandwidth of <3 MHz, but out of band ASE becomes significant @ ~10 dB down
- Backward pumping produces clean spectrum (>45 dB side-mode and ASE suppression) but with output limited to ~ 3 W peak from the amplifier
- Implemented at 1262 nm to take advantage of trough between two lines
- Clean modulation demonstrated for both forward and backward pumping schemes

Spectrum Forward vs. Backward Pumping

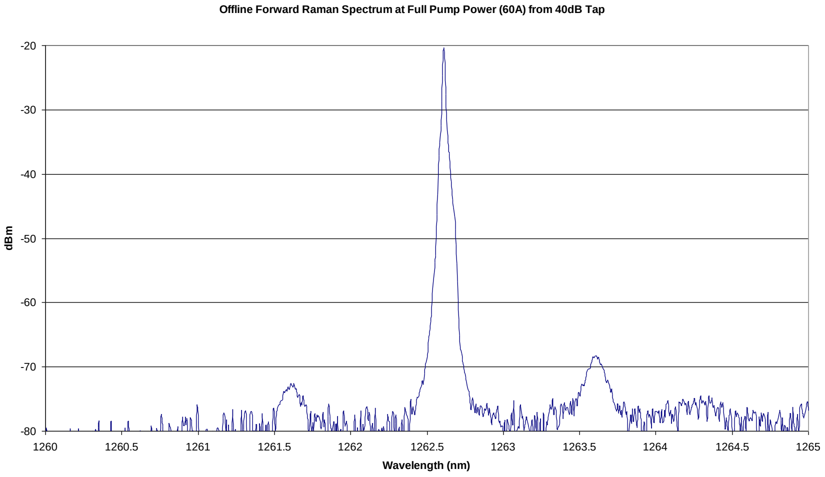
Forward Pumping

13.2 W peak, 3 dB bandwidth ~3 MHz



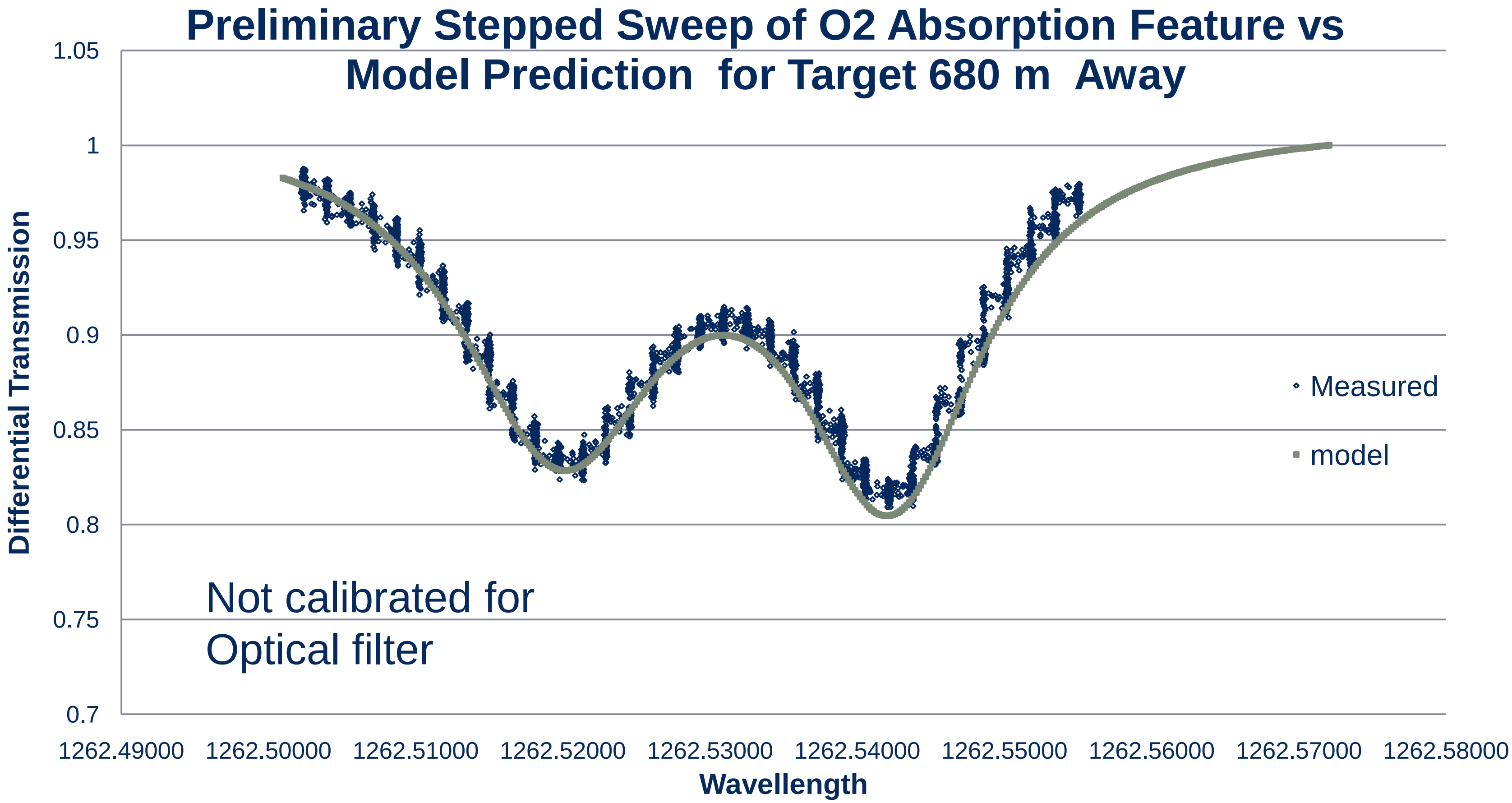
Backward Pumping

2.4 W peak, 3 dB bandwidth ~2 MHz



Major loss for backward pumping is efficiency. Need longer fibers/more SBS suppression

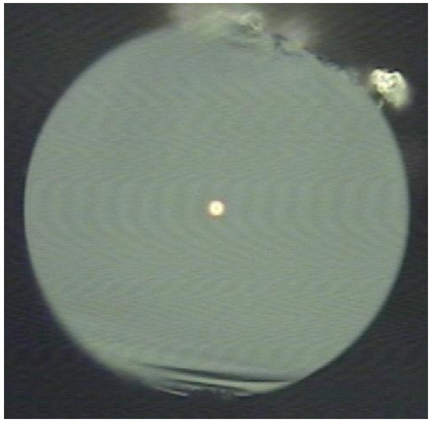
Initial Ground Measurements with 2nd Generation Amplifier (Backward Pumping)



Ongoing Fiber Development

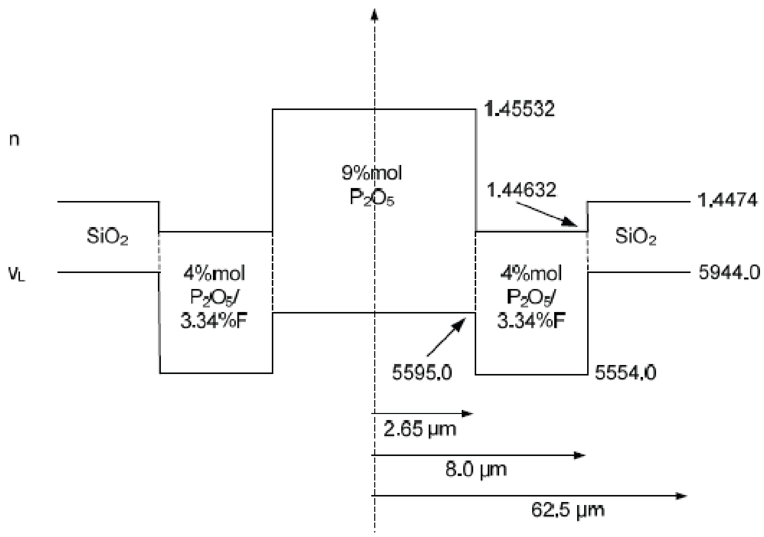
First fiber with acoustic guiding layer had irregular core shape and guided significant light in the inner cladding

Adjustments were made to the heating elements used to collapse the MCVD tube which has resulted in circular cores on subsequent fibers

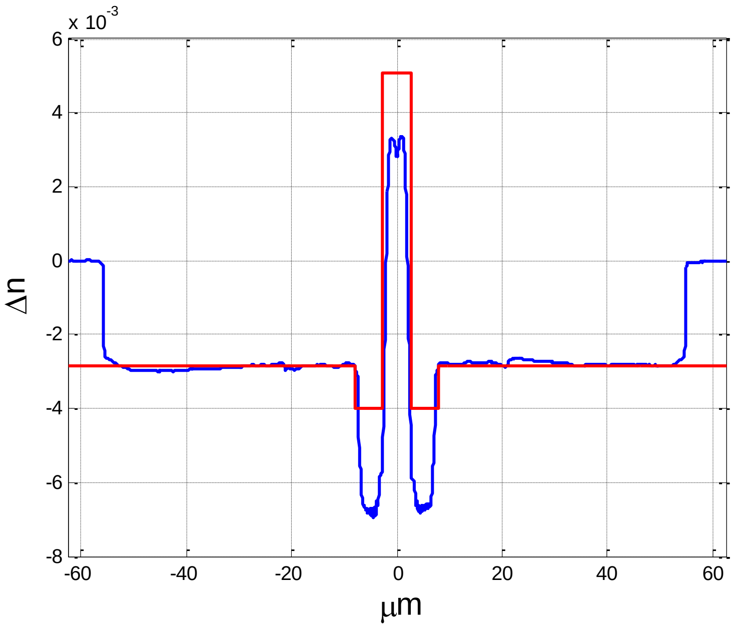


Recent Work to Obtain Required SBS Suppression

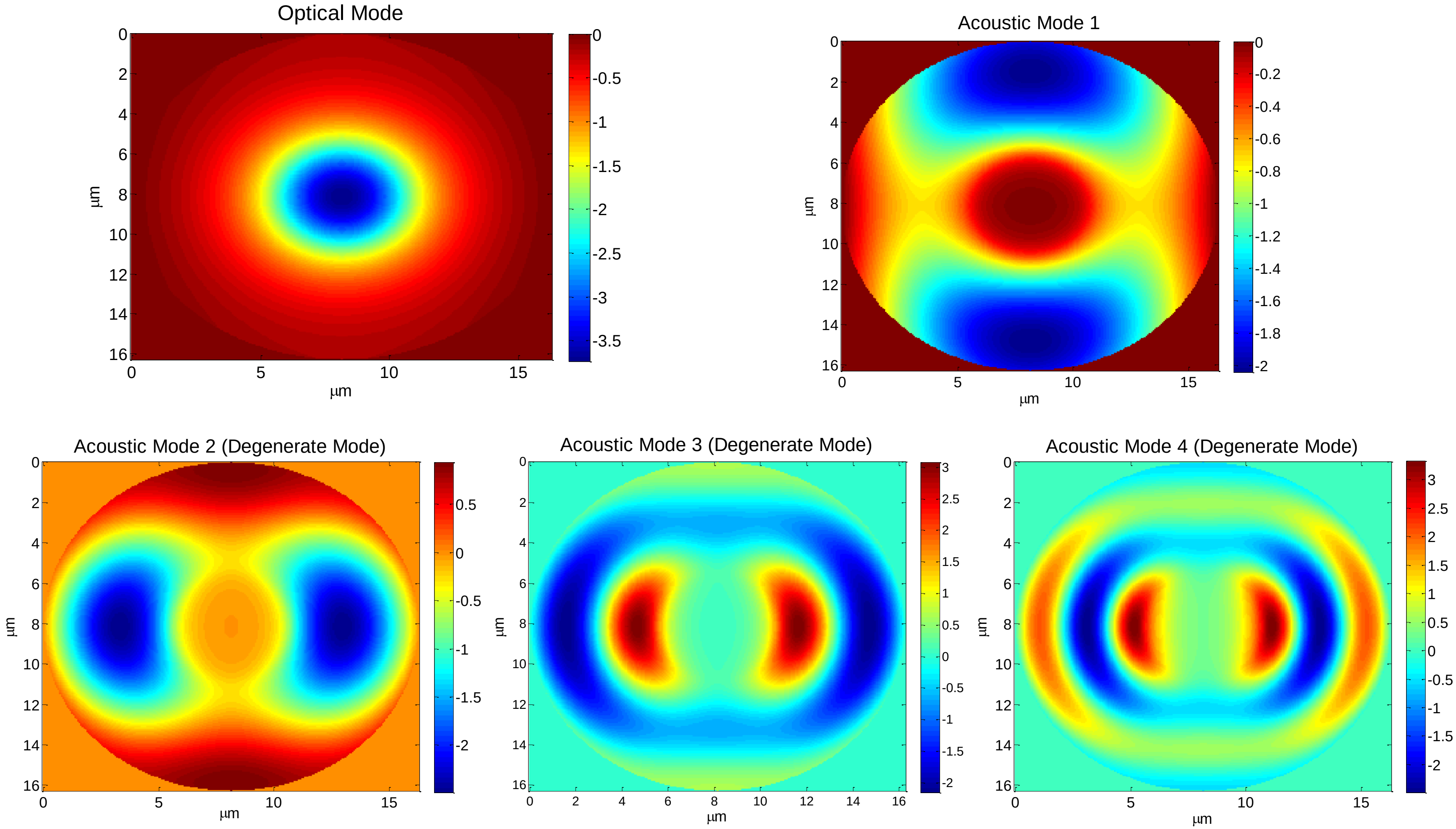
Latest iterative fiber design



Results from latest preform

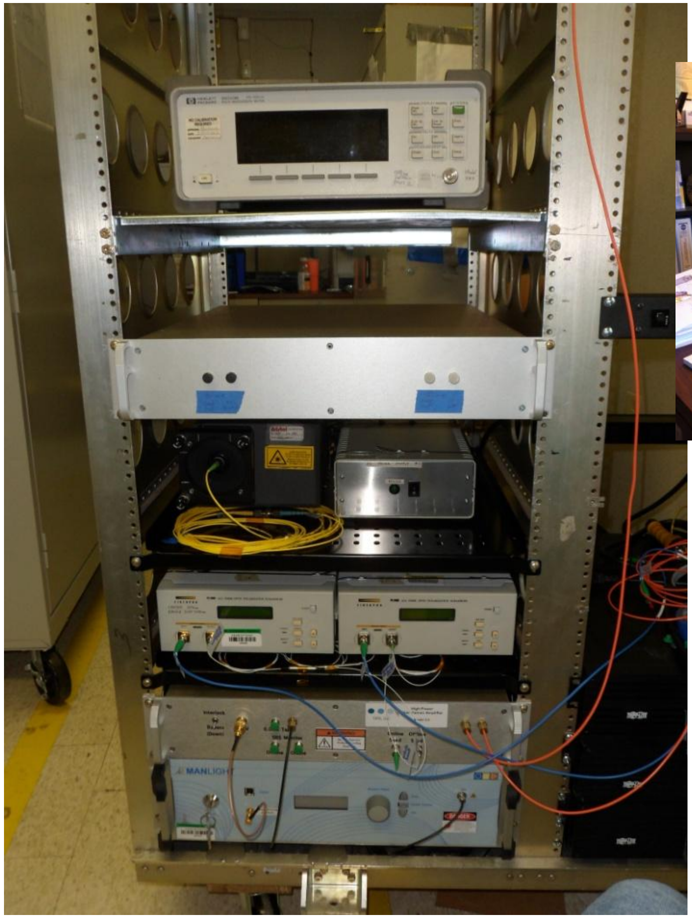


Fiber Design Performance Modeling



Packaging Amplifier for DC-8 Flights

- HP wave meter for monitoring offline wavelength
- Seed laser and modulation box
- Bristol wave meter for monitoring online wavelength
- Polarization control
- Raman amplifier
- Pump Laser



Detector is being provided by LaRC

Current and Future Work

- Second generation amplifier is currently at ITT and is being packaged into a DC-8 rack and integrated with the CO_2 EDU
- Ground tests are being conducted over the next two weeks.
- Flight testing is planned for July and August on the NASA DC-8 aircraft.
- New single mode fibers compatible for splicing with Hi-1060 fiber have been manufactured and are being evaluated for their acoustic profiles and doping concentrations.
- We are currently pursuing funding to exploit the progress we have made in the design and manufacture of acoustic guided fibers for this wavelength. With plans to combine the varying core diameter approach for maximum SBS suppression.

Acknowledgements

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- Additional collaborators:
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  - TIPD, LLC, & College of Optical Sciences – Nasser Peyghambarian and Robert Norwood
  - AER – Hilary E. Snell

Questions?